

Tree establishment for a temperate agro-forest in central Appalachia, USA[★]

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Abstract

Small farms in Appalachia are economically challenged due to complex topography and soil constraints that limit productivity. Most farms have considerable acreage in forest, some of which is on the least productive sites, which contributes little income. The purpose of this study was to determine management and microclimate impacts on the establishment of an agro-forest for increasing the economic value of the forested land resource. A 1.2 ha forest clear-cut was planted with red oak (*Quercus rubra*) as the desired mature forest species alternated with rows of Chinese chestnut (*Castanea mollissima*), pawpaw (*Asimina triloba*), hazelnut (*Corylus americana*), and white pine (*Pinus strobus*) for generating income as the forest matures. Oak and chestnut required protection from deer. Oak had the lowest survival rate (61%) and chestnut had the highest survival rate (94%). While providing protection, Tubex plastic tubes also resulted in spindly tree growth. Plastic tubes did, however, improve pawpaw survival. Oak did best on well-drained locations. Chestnut and hazelnut were negatively impacted by forest edge more than oak or pawpaw. Overall there was a high degree of variability in tree growth suggesting that on low productivity sites, a planting density substantially higher than the desired final stand may be warranted to optimize the tree-vigor/micro-site match.

Introduction

The hilly Appalachian Region in the US is composed of parts of 11 states and is $5.05 \times 10^4 \text{ km}^2$ making it 23% larger than the state of California. The region has a temperate climate and is dominated by hardwood forests having much greater species diversity compared to what the early European settlers were accustomed (Braun 1950). Post-logging erosion and fires degraded soils in many areas in the late 18th, 19th, and early 20th century (Clarkson 1964). There is concern about increased

future soil degradation as a result of shorter harvesting rotations and whole tree harvesting to supply the many recently constructed chip mills (Johnson et al. 1982). In this high rainfall region, most of the nutrients are tied up in biomass on shallow-soil sites, thus site productivity may be compromised by frequent complete removal of above-ground biomass. There is additional concern over increased cation leaching as a result of nitrogen and sulfur deposition from acid rain (Adams 1999).

While there are some highly productive agricultural regions within Appalachia, most of it is marginally productive and it is instead hilly and difficult to farm (Barnes 1938; Proctor and White 1962). These hilly regions contain small,

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labor-intensive farms and soils that are susceptible to erosion with nutrients readily leached by the high rainfall. Until well into the 20th century, agriculture persisted through a land-use rotation process that exploited the ability of woody vegetation to capture and accumulate nutrients. Woody vegetation was cut and burned to release nutrients, which allowed production of annual grains such as corn, wheat, or oats for several years. The land was then used as pasture for a few additional years before allowing woody vegetation to again reclaim the field (Hart 1977; Otto 1983). Currently most small farms in Appalachia have little if any crop land. They are a pasture and woodland mosaic.

With the recent interest in temperate agroforestry in North America, agroforestry principles may be applied to low-productivity sites that may increase small farm income and improve on-site nutrient retention compared to traditional forestry or agriculture. There are many examples in tropical regions of planting forests or managing existing forests to develop highly productive areas that require little management and function similar to forest ecosystems (Michon and de Foresta 1999). These systems provide a variety of food products in addition to wood. There is some evidence that in temperate North America agro-forests were managed by indigenous tribes prior to European settlement (Wykoff 1991). There has been no effort to scientifically study the feasibility of developing agroforests for North America.

The objective of this research was to determine management, site characteristics, and microclimate impacts on establishing a humid, temperate agroforest within a forest group-selection clear-cut. The long term goal is to reestablish a hardwood forest for high value veneer with a long rotation time to help conserve site soil nutrients thus maximizing sustainability yet provide short-term income from nuts and fruits for several decades while the oak canopy is developing.

Materials and methods

This research was located on the grounds of the USDA-ARS Appalachian Farming Systems Research Center, Beaver, West Virginia, US which is 37°47' N, 81°07' W and at an elevation of 780 m. Precipitation averages 1.1myr^{-1} and is

distributed fairly evenly throughout the year. Soil at the site was mapped as a Rayne silt loam, a fine-loamy, mixed, mesic, Typic Hapludult. The research site was second growth forest comprised mostly of white oak (*Quercus alba*), red maple (*Acer rubrum*) and scarlet oak (*Quercus coccinea*) with their canopy top at about 25 m and an understory of sapling white pine (*Pinus strobus*).

In the winter of 1998 a 30 by 400 m clearcut was made on a near level site (slope <2%) with the long dimension oriented east-west. This orientation created a solar radiation gradient across the width such that at the equinox about half the clearing was shaded to some degree. The pine sapling understory was removed an additional 30 m from all clearing edges so that it did not contribute a changing edge effect component from the increased light availability. Because of resource limitations, the agro-forest plot only occupied the middle 200 m of the clear-cut which also minimized effects due to differences in early or late day shading across the plot. All trees were planted during the spring and summer of 1998.

The basic design involved making a 1.2 ha group-selection clear-cut and managing the way in which the forest regenerated to facilitate specialty crop harvests for the first few decades. The forest is to be eventually dominated by red oak (*Quercus rubra*) for a high value timber crop. The oak were planted in rows 12 m apart. In the center between oak rows, three other species adapted to the Appalachian region, with shorter mature canopies, Chinese chestnut (*Castanea mollissima*), hazelnut (*Corylus americana*), or pawpaw (*Asimina triloba*), were planted in rows for diversified harvests of nuts and fruit (Figure 1). All species were 30–50 cm tall and planted bare root except pawpaw which was potted. This gave a 6 m spacing between woody perennials with these specialty crop components' production targeted to begin within 5–10 years. Not included in this analysis, since they were not planted in the initial establishment year, are rows midway between the above mentioned species of either blackberry (*Rubus* spp.) or blueberry (*Vaccinium* spp.) intended for harvests starting in the 2–3 year time frame.

There were 9 rows of oak oriented north-south across the clearing. There were three row-treatments for oak randomized within the plot length. There were 4 rows of trees 1 m apart with an establishment treatment consisting of protection

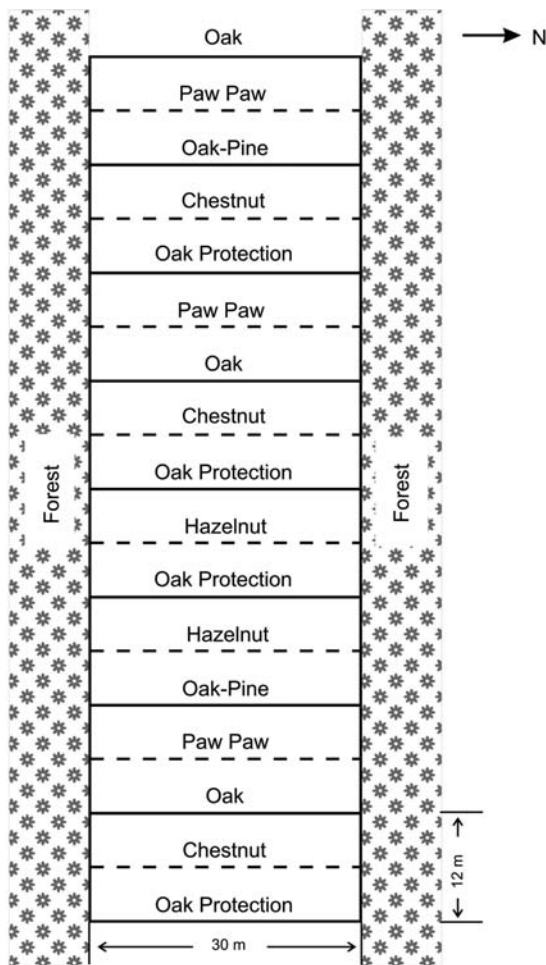


Figure 1. Plot diagram of the research site showing location of tree species and establishment treatments.

from deer browse using 1.5 m plastic Tubex Tube Shelters, protection using 0.9 m mesh Rigid Seedling Protector Tubes, and no protection. There were three rows with trees 1.5 m apart and all trees had 1.5 m tube shelters. There were 2 rows with oak in tube shelters 3 m apart but with a white pine (15 cm, bare root) between each and a row of pine 1.5 m apart in rows 1.5 m on either side. This put these oaks in the middle of a square consisting of 8 pine. The pine were pruned as dense-foliage, cone-shaped holiday trees for an additional short term potential income source.

Between oak rows there were 3 rows of chestnut with the same three establishment treatments as the oak establishment, 1.5 m tubes, 0.9 m mesh or no protection. There were also 3 rows of pawpaw that had either 0.6 m tubes or no protection and 2

rows of hazelnuts with the same three protection treatments as oak and chestnut except the tubes were 0.6 m. All planted deciduous species had a 10 g, twelve month release fertilizer packet (16-6-8) placed under the root system at planting, and buried 15 cm to the north and south of each, at 10 cm depth, at the start of the third growing season. Occasional spot application of glyphosate and mowing with weed-eaters was done to control undesirable vegetation between rows.

Site soil characterization was done for a 25 point grid across the planted area for 0–10 and 10–20 depth increments (Table 2). Particle size analysis was done using the pipette method (Gee and Bauder 1986). Soil chemical analysis consisted of pH in H₂O (1:1) and S, Mn, Mg, Ca, Al, Na, and K by ammonium acetate soil extracts using ICP (Thomas 1982). Soil depth was measured for a 45-point grid using a thin sharpened rod which was pushed into the soil until striking rock. There were a few small rock outcrops which were avoided.

Soil moisture was measured weekly during the growing season for the soil top 15 cm using a Trime-FM TDR soil moisture meter. Soil moisture was measured at plot edges and every 6 m along each row containing red oak. Wind speed profiles within the clearing were measured at 2 m for the year 2001 with a grid of 9 Belfort mechanical totalizing anemometers that had been calibrated with a 03101-5 R.M. Young Wind Sentry Anemometer. The Wind Sentry anemometer was subsequently installed on the roof of a two story building on a hill about 100 m outside the clearing placing it near the height of the tree tops around the clearing. Photosynthetically active radiation (PAR) was measured using a system of 16 Li-Cor Line Quantum Sensors oriented east–west along oak rows 2, 4, 6, and 8, at 1, 5, 9, and 13 m from the south side of the clearing at 30 cm above ground level. After the fall equinox, additional data were collected at 17, 21, 25, and 29 m from the south side.

At the end of each of the four growing seasons all species were evaluated to determine survival. Those surviving had their height and stem diameter (10 cm above the ground) measured except for pine since they were pruned as holiday trees. Stem diameter was not measured the last 2 years for pawpaw and hazelnuts since they became shrubby, with hazelnuts having multiple stems, and pawpaw developing numerous root sprouts. Hazelnut height was only measured the last 3 years since they

were planted at the end of the first growing season. Effect of protection treatment, soil depth, soil moisture under wet conditions, soil moisture under dry conditions, and distance from forest edge, on survival was analyzed using logistical regression. Correlation between growth and distance from forest edge was determined using linear regression. Impact of protection treatment on tree height and stem diameter was determined using analysis of variance and Tukey (HSD) separation of means.

Results

Site characteristics

Particle size analysis indicated the soils of the planted area were a sandy loam rather than a silt loam as mapped (Table 1). Consistent with this texture, exchangeable ion concentrations were low except for K which by agricultural soil standards was very high. There were no major trends in soil characteristics across the site. Soil depth did show a trend of being shallower along the north and south edges than within the middle (Table 2).

Growing season precipitation was near normal during the 4 years of this study phase. The planting year had slightly above normal precipitation, the second year had slightly below normal, with the two remaining years close to normal (Table 3). The driest period was May and June of 1999 when precipitation was only about one third of normal. Volumetric soil moisture for that period was the lowest measured but still averaged above 20% across the study site (Figure 2). Soil moisture depletion (average soil moisture for periods above 40% minus average soil moisture for the period below 25%) was about twice as great along the north and south plot borders during this period

Table 2. Average soil depth as a function of distance from clearing north edge.

Distance from N (m)	3	9	15	21	27
Average depth (m)	0.40	0.56	0.57	0.46	0.36
Standard deviation (m)	0.16	0.16	0.28	0.24	0.07
Grouping	ab	a	a	ab	b

Depth in same groupings are not significantly different at the 0.05 rejection level using the Tukey (HSD) comparison of means.

compared to the center presumably due to utilization by forest trees along these borders (Table 4). However, rather than lack of soil moisture being a limitation, some parts of the site tended to stay very wet so that average soil moisture values are higher much of the time compared to what would be expected for a sandy loam.

Daily total photosynthetically active radiation (PAR) at the southern plot border for sunny conditions was 42% of the level in the center at summer solstice and decreased to 9% by October 1 which was 10 days past fall equinox (Figure 3). At summer solstice the sun is only 15° from vertical but the angle increases to 37.5° by fall equinox at this latitude. The result is that not only does the shade extend further into the plot by fall equinox but more of the sun is intercepted by vegetation along the path through the forest canopy, thus reducing incident sunflecks within the shaded area.

Relative to the plot centers, the south plot edge received more PAR on overcast days than sunny days since incident PAR was diffuse and a function of the amount of open sky in the field-of-view unobscured by trees. The south plot edge received 59% of the plot center levels. The north plot edge received less PAR on overcast days compared to sunny days since on sunny days it received no shading yet on overcast days it had the same relative field-of-view obscured by trees as the south edge (Figure 3). The absolute PAR received varied

Table 1. Mean site soil chemical and physical properties.

	Exchangeable ion concentration ($\mu\text{g g}^{-1}$)							pH	Particle size (%)		
	S	Mn	Mg	Ca	Al	Na	K		Sand	Silt	Clay
0–10 cm											
Mean	62	83	26	150	32	6.4	148	4.8	65	29	6
Standard deviation	22	67	13	80	16	2.6	55	0.3	7	6	3
10–20 cm											
Mean	106	32	9	37	28	5.2	78	4.8	59	30	11
Standard deviation	40	36	6	31	13	1.6	36	0.2	8	6	4

Table 3. Growing season precipitation data from AFSRC.

Months	1998 (mm)	1999 (mm)	2000 (mm)	2001 (mm)	30 years average (mm)
March	87	94	63	65	86
April	112	84	104	32	87
May	178	33	88	191	101
June	171	30	117	78	98
July	91	87	137	247	119
August	42	86	140	41	86
September	42	106	74	36	85
Total	723	520	723	690	662

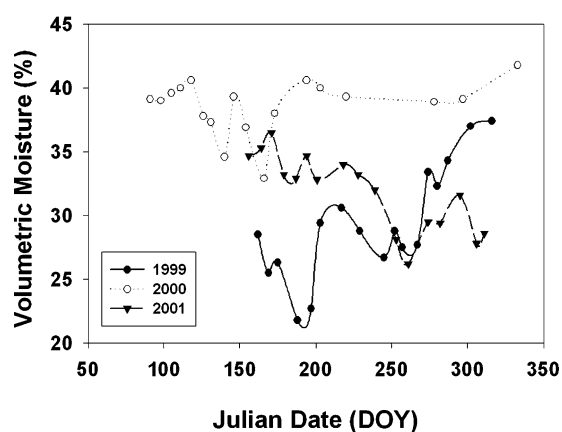


Figure 2. Average site soil moisture percent (by volume) in the top 15 cm for the 1999, 2000, and 2001 growing seasons.

Table 4. Maximum soil water depletion during the study as a function of distance from north.

Distance (m)	0	6	12	18	24	30
Depletion (%)	24	16	12	16	20	27
Standard deviation (%)	7	7	4	3	7	4
Grouping	ab	cd	d	cd	bc	a

Depletion percent within the same grouping are not significantly different at the 0.05 rejection level using the Tukey (HSD) comparison of means.

throughout the growing season since incident PAR is about a third less at fall equinox than at summer solstice.

Average wind velocity was partitioned into the growing season period when the trees around the plot were in leaf, and pooled data from spring and autumn periods without leaves. Average wind velocity was roughly half as high when the trees were in leaf compared to when without (Table 5). The velocity across the width was not statistically different during the leafless period, however, the south

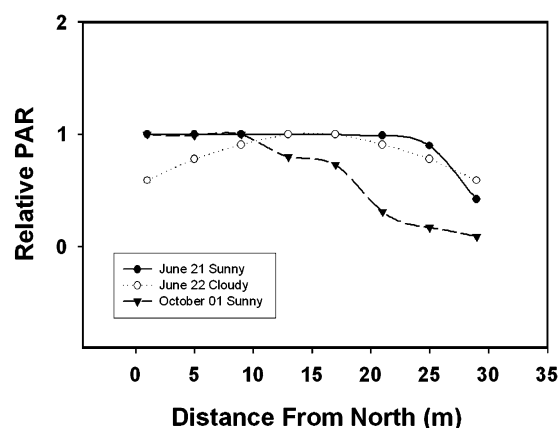


Figure 3. Relative photosynthetically active radiation across the clearing for a sunny and a cloudy day at summer solstice and for a sunny day after fall equinox.

Table 5. Average wind velocity at 2 m across the clearing during periods with full leaf cover on trees and without.

Forest tree status	Average seasonal wind velocity (km hr ⁻¹)			
	North	Middle	South	Roof
Without leaves	2.8 a	3.0 a	2.6 a	6.6
With leaves	1.5 ab	1.9 a	1.2 b	4.4

Values in horizontal rows followed by the same letter are not significantly different at the 0.05 rejection level using the Tukey (HSD) comparison of means.

edge averaged a statistically significant 37% less than the plot middle during the growing season. The plot middle region averaged about 45% of the wind velocity on the roof top for both periods.

Tree response

Tree survival rate varied widely between species. Oak had the lowest survival rate at 61% and

Table 6. Survival rate of planted tree species at the end of the 4th growing season.

Species	Survival (%)
Oak	61
Chestnut	94
Pawpaw (total)	67
With tubes	83
Without tubes	49
Hazelnuts	83
Pine	69

chestnut had the highest survival rate at 94% (Table 6). Of the 20 relationships tested by logistical regression (protection treatment, soil depth, soil moisture under wet conditions, soil moisture under dry conditions, and distance from forest edge for oak, chestnut, pawpaw, and hazelnut) only two relationships were significant, and both were highly significant ($p < 0.01$). There was a negative correlation between soil moisture under wet conditions and survival of oak indicating oak preferred well drained sites. The other significant trend was that pawpaw had a much higher survival rate when planted seedlings were protected with tubes (Table 6).

The protection status of all species influenced early growth of all four deciduous species however there was a complicating factor. Deer browsing heavily damaged oak and chestnut trees with no protection the first growing season and pruned those protected by mesh to mesh surfaces. It became evident that these treatments would not survive without more protection. During autumn of 1998 a ten foot electric fence was erected around the entire plot area so that all trees were protected from deer the winter of 1998 and the following 3 years. At the end of the first growing season all species in protection tubes were taller than without any protection (Table 7). Oak and chestnut were also taller in tubes than in mesh. After 4 growing seasons only chestnut was taller in tubes than in mesh or without protection. After four growing seasons both oak and chestnut were significantly smaller in diameter 10 cm above the ground in the tube protection treatment compared to with no protection.

At the end of 4 years the chestnut trees averaged more than twice as tall as oak, hazelnut, or pawpaw. Their stem diameter also averaged more than twice that of oak for all protection treatments

Table 7. Growth by year of planted deciduous tree species.

Species	Year	Protection type		
		Tube	Mesh	None
Tree Height (m)				
Oak	98	0.54 a	0.44 b	0.44 b
	99	0.80 a	0.58 b	0.46 b
	00	1.03 a	0.85 ab	0.69 b
	01	1.19 a	1.05 a	0.89 a
Chestnut	98	0.93 a	0.64 b	0.44 c
	99	1.46 a	0.94 b	0.57 c
	00	1.84 a	1.50 b	1.28 b
	01	2.58 a	2.14 b	1.84 b
Hazelnut	99	0.41 a	0.33 ab	0.25 b
	00	0.68 a	0.53 a	0.50 a
	01	0.93 a	0.87 a	0.75 a
Pawpaw	98	0.41 a		0.19 b
	99	0.69 a		0.32 b
	00	0.89 a		0.63 b
	01	1.12 a		1.02 a
Tree diameter (cm)				
Oak	01	1.3 b	2.5 a	2.1 ab
Chestnut	01	3.7 b	5.1 a	4.4 ab

Values in horizontal rows followed by the same letter and not significantly different at the 0.05 rejection level using the Tukey (HSD) comparison of means.

(Table 7). By the end of the fourth growing season the pawpaw in the no protection treatment also surpassed the unprotected oak in height.

There were three different types of treatment rows containing oak in tubes. One evaluated different levels of sapling protection, a second evaluated sapling growth among white pine saplings, and a third consisted of all oak in tubes. At the end of 4 years there was no significant difference in tree height or diameter between these three row treatments (Table 8) so for the analysis of position effects within the plot area these data were pooled.

There was no significant relationship between oak height in the tube protection and proximity to either north or south border of the plot area (Figure 4a). The variability in tree height was high with a few trees over 2.5 m tall and many under 0.5 m. Stem diameter was also highly variable with a few trees greater than 3 cm but most under 1 cm (Figure 4b). Stem diameter showed a slight decrease from the middle towards both north and south edge but the trend was not significant at the.

All protection treatment data was pooled for analysis of plot edge effects for chestnut which

Table 8. Size of oak trees within protection tubes for three planting treatments.

Treatment	Height (m)	Diameter (cm)
Oak protection	1.19 a	1.3 a
Oak with pine	1.06 a	1.5 a
Oak alone	1.28 a	1.6 a

Values in vertical columns followed by the same letter are not significantly different at the 0.05 rejection level using the Tukey (HSD) comparison of means.

grew much more vigorously on the site than oak with more trees over 3 m in height than under 1 m (Figure 4c). The decrease in tree height near the south edge compared to plot center was highly significant ($p < 0.01$). There appeared to be a slight

decrease in height near the north edge but it was not significant. The depression of stem diameter near the north edge (Figure 4d) was significant and near the south edge was highly significant.

There was a significant decrease in pawpaw height near the north edge compared to the plot center but not near the south edge (Figure 4e). In spite of the lack of significance for the south edge there is an apparent decrease in height of the tallest trees with increasing proximity to the south edge but there is a large variability in tree height. Hazelnut height decreased dramatically, and it was highly significant (Figure 4f), as distance from the south edge decreased. There was no significant decrease as a function of distance from the middle to the north edge.

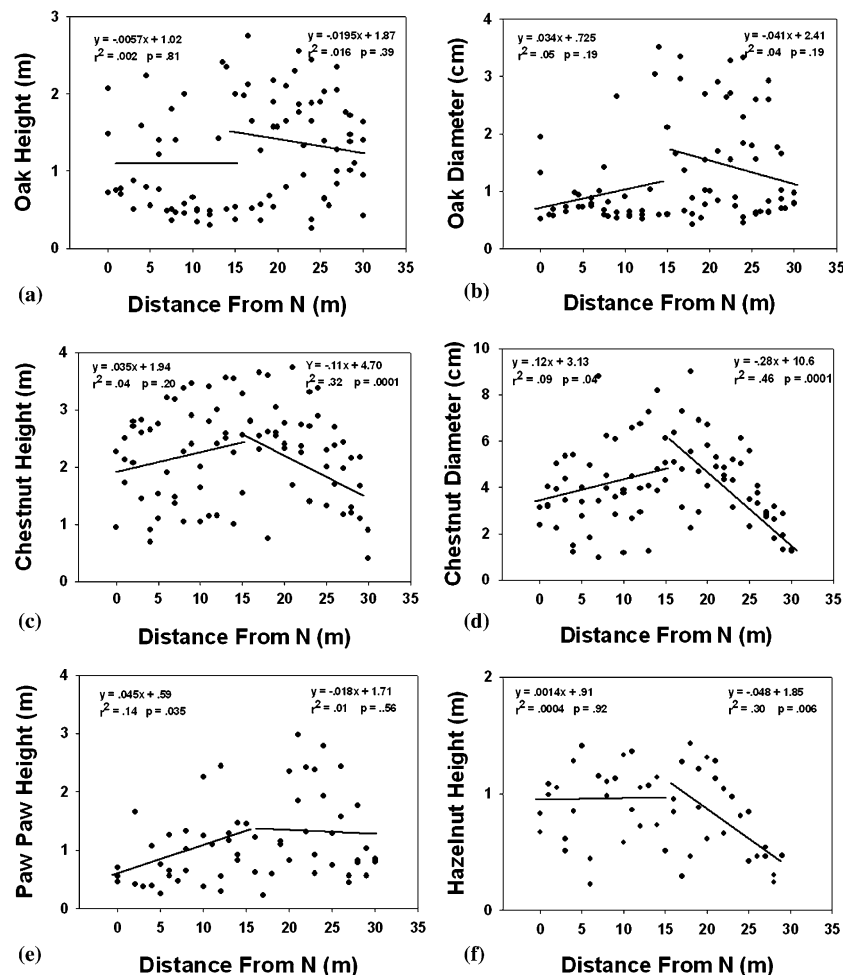


Figure 4. Height of oak (a), chestnut (c), pawpaw (e) and hazelnut (f) and stem diameter 10 cm above the ground of oak (b) and chestnut (d) as a function of distance from the gap's north edge after 4 growing seasons.

Discussion

There was a tremendous amount of variability in overall tree growth across this study site. This variability is related to each tree's genetic potential for exploiting the availability of resources at the site where planted. At the plot edges the planted trees were in competition with existing forest for these resources, at both edges for water and nutrients, and at the south edge for PAR where existing forest shaded. Both chestnut and hazelnut showed a statistical decrease in growth that might be attributed at least in part to shading but oak and pawpaw did not. Chestnut stem diameter and pawpaw height were impacted by resource availability other than shading on the north edge. On the north edge the pawpaw, which is normally an understory tree growing best under partial shade (Pomper et al. 2002), may have been negatively impacted by too much PAR relative to other resources since survival was improved by tube shelters which attenuated PAR the first two growing seasons.

Sapling growth was better in the center of the cleared strip where wind was also higher. In the UK, (Proe et al. 2001) measured 40% higher wind in a whole tree removal logged site than in a conventional stem removal logged site. Planted saplings had 24% increased growth at the higher wind site and had cooler foliage temperature during summer months. It is not certain in these two studies if higher wind was a factor in increased growth or merely a coincidental correlation.

Edge effect growth inhibition, where seen, was dominantly exhibited in the first 5 m. This analysis is of survival and growth during the first 4 years and may not accurately predict yield of nuts, fruit, or even timber several decades into the future. A high initial planting density is warranted in a challenging site such as this in order to insure a good final stand of vigorous trees with good economic potential.

There are several ways in which an actual production site should be developed differently than this research site. Since the north and south edges produced generally inferior crop trees, it is probably not economically desirable to plant the end 3 m especially since these areas would be useful as access lanes for equipment. The rigorous adherence to a set planting spacing could also be altered to avoid exceptionally rocky or wet spots. Had this been done for the research site tree survival would

likely have been higher. There is also no reason for a production site to maintain single-species rows of crop trees. A shade tolerant tree such as pawpaw could be planted on the southern row end and sun loving species such as chestnut or hazelnut on the northern.

Deer were a serious problem for establishing saplings at this site as they are in much of the eastern USA including Appalachia. Plastic tubes provided effective protection for red oak and facilitate increased height growth but resulted in spindly saplings as others have found (Lantagne et al. 1990; Ponder 1995; Ward et al. 2000). However, planting each sapling in a plastic tube is expensive and electric fencing is more cost effective and provides good protection for gaps of substantial size (Kays 1996). Developing an agroforest on a group selection cut site will require some form of deer protection that will be dependent on crop tree species desired and management objectives of land owners.

While most work studying the effect of plastic tubes on early tree growth has been with red oak which responds well, not all tree species respond favorably to establishment in plastic tubes. (Kjelgren and Rupp 1997) measured decreased growth by Norway maple (*Acer platanoides* L.) and green ash (*Fraxinus pennsylvanica* Marsh). In our study chestnut was heavily browsed before installing the electric fence likely due to its tannin content (Verheyden-Tixier and Duncan 2000). Chestnut protected by tubes grew better than those in mesh or without protection (Table 7). It is not clear if the tube itself affected growth or merely protection from browse damage the first year gave that treatment an advantage over the other two.

Agroforests have the potential to increase and diversify income sources from land considered marginal for traditional agricultural enterprises in Appalachia. Returning recently logged land to woody vegetation with a long rotation time producing a high value veneer crop, and a succession of crops compatible with a developing mature forest, may help conserve soil nutrients and long-term site productivity.

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